Advanced solid-state lasers 2019: Focus issue introduction

Optics EXPRESS

Advanced Solid-State Lasers 2019: focus issue introduction

Alphan Sennaroglu,[1,2,*] Gregory Goodno,[3] Sergey Mirov,[4,5] Johan Nilsson,[6] Alan Petersen,[7] Irina Sorokina,[8] and Stefano Taccheo[9]

[1] *Departments of Physics and Electrical-Electronics Engineering, Koç University, Istanbul 34450, Turkey*
[2] *Koç University Surface Science and Technology Center (KUYTAM), Istanbul 34450, Turkey*
[3] *Northrop Grumman Aerospace Systems, Redondo Beach, CA 90278, USA*
[4] *IPG Photonics – Southeast Technology Center, 100 Lucerne Lane, Birmingham, AL 35211, USA*
[5] *University of Alabama at Birmingham, 1530 3rd Ave S, Birmingham, AL 35294, USA*
[6] *Optoelectronics Research Center, University of Southampton, Southampton SO17 1BJ, United Kingdom*
[7] *Spectra Physics/MKS Instruments, 3635 Peterson Way, Santa Clara, CA 95054, USA*
[8] *Norges Teknisk Naturvitenskapelige University, Norway*
[9] *Swansea University, Bay Campus, SA1 8EN Swansea, United Kingdom*
[*] *asennar@ku.edu.tr*

Abstract: This joint issue of *Optics Express* and *Optical Materials Express* features 17 state-of-the art articles written by authors who participated in the international conference Advanced Solid-State Lasers held in Vienna, Austria, from September 29 to October 3, 2019. This introduction provides a summary of these articles that cover numerous areas of solid-state lasers from materials research to sources and from design to experimental demonstration.

Advanced solid-state lasers (ASSL) is an international conference devoted to recent advances in both materials and sources aspects of solid-state lasers. The materials section covers advances in optics, materials science, condensed matter physics, and chemistry relevant to the development, characterization, and applications of new materials and components for lasers and photonics. These include crystals, glasses, and ceramics, as well as functionalized composite materials, from fibers and waveguides to engineered structures with pre-assigned optical properties. Materials used for the fabrication of basic laser components also belong to a core part of this topic. Coherent and high-brightness radiation sources include lasers as well as pump and nonlinear devices. Emphasis is on advances in science and technology, for improved power, efficiency, brightness, stability, wavelength coverage, pulse width, cost, environmental impact, or other application-specific attributes.

We hope that readers will enjoy this joint feature issue of 17 top-level articles which cover recent advances in both materials and sources aspects of solid-state lasers. We thank all the authors and reviewers for their important contributions. We are especially grateful to Carmelita Washington, Keith Jackson, and John Long from the OSA staff for their outstanding work throughout the launch of this feature issue as well as the review and production processes.

Development of novel materials processing schemes, spectral filters, and resonator architectures paves the way for the design of next generation solid-state lasers. K. Hasse and C. Kraenkel reported on fast, direct laser inscription of waveguide laser structures with a 1 MHz-repetition rate fs-laser. They inscribed and characterized more than 100 tracks in Yb:CALGO crystals and waveguide lasing was achieved with slope efficiencies of up to 57% under pumping with an optically pumped semiconductor laser [1]. V. Llamas *et al.* employed femtosecond direct-laser-writing at kHz repetition rates to produce depressed-index buried and surface channel waveguides (type III) in a bulk 3.5 at.% Tm^{3+}:CALGO crystal and characterized the waveguides using confocal microscopy and Raman spectroscopy. In-band pumping at 1679 nm generated a

#396121 https://doi.org/10.1364/OE.396121
Journal © 2020 Received 24 Apr 2020; published 1 May 2020

Optics EXPRESS

maximum continuous-wave output power of 0.81 W at 1866-1947 nm with a slope efficiency of 71.2% with respect to absorbed pump power [2]. In another study, Y. Baravets *et al.* used a new type of metallic resonant leaky-mode diffraction grating to construct a fiber laser that is broadly tunable in the wavelength range from 1058 nm to 1640 nm. Experimentally measured diffraction efficiency of more than 90% was obtained into the first reflected order over the 1417-1700 nm spectral window [3]. Q. Berthome *et al.* further used a volume Bragg grating and a YAG etalon to construct an actively Q-switched, single longitudinal mode Tm:YAP laser which generated 230μJ, 50 ns pulses at 1 kHz and which was tunable from 1940 to 1960 nm [4].

Attaining improved performance of coherent sources in terms of energy, power, and brightness scaling is among the major targets of research in solid-state lasers. Mackonis and Rodin reported a compact optical parametric chirped-pulse amplifier (OPCPA) that is scalable to TW peak power. By using 1.2 ps pump pulses delivered from a Yb:YAG laser, they achieved amplified pulse energy of 2.1 mJ in a three-stage OPCPA [5]. L. Rishoj *et al.* employed the process of soliton self-mode conversion in a multi-mode fiber to demonstrate an energetic, dual-wavelength ultrashort pulsed fiber source which delivers pulses at the wavelengths of 1205 and 1273 nm with pulse energies of 30 nJ [6]. In another study, Y. Chen *et al.* employed a graded-index passive fiber to construct a high-power continuous-wave Raman fiber amplifier and achieved 2.087 kW at 1130 nm with an optical conversion efficiency of 90% [7]. W. Wu *et al.* further reported on a sub-nanosecond burst-mode MOPA Nd:YAG laser at 1.06μm. Output energies of 29.8 mJ and 81 mJ were obtained during 1 kHz and 10 Hz operation, respectively, resulting in peak power of as high as 90 MW during 10 Hz operation [8].

Nonlinear frequency conversion techniques play a crucial role in attaining new spectral ranges with solid-state lasers. F. Cassouret *et al.* reported on efficient third harmonic generation at 355 nm by using the single crystal $Ca_5(BO_3)_3F$ (CBF). The output of a high peak power, passively Q-switched Nd^{3+}:YAG/Cr^{4+}:YAG microlaser was mixed with its second harmonic in the CBF crystal, resulting in the generation of 479-μJ, 568-ps pulses at 355 nm with a peak power of 0.843 MW [9]. In another study, G. Scurria *et al.* reported on the first experimental demonstration of multi-watt level mid-infrared super continuum generation in an InF_3 fiber. They used a single, actively Q-switched mode-locked Tm^{3+}-doped fiber oscillator with an average output power of 15 W and generated a supercontinuum with a maximum all bands output power of 7W. The spectrum extended up to 4.7 μm [10]. Furthermore, J. T. Meyer *et al.* employed a passively mode-locked vertical external cavity surface emitting laser (VECSEL) to produce green output at 528 nm based on intra-cavity second harmonic generation in a lithium triborate crystal. They obtained 760-fs pulses at 528 nm, at a pulse repetition rate of 465 MHz and with an average output power of 230 mW [11]. Finally, M. Li *et al.* reported on the first demonstration of second Stokes lasing in a diamond Raman ring cavity laser resonantly pumped by a continuous-wave tunable Ti:sapphire laser. A maximum output power of 364 mW was generated at 1101.3 nm with a slope efficiency of 33.4% [12].

Search for new laser gain media and characterization of optical materials play a crucial role in the development of new solid-state lasers and resonator components. A. Volokitina *et al.* reported on the crystal growth, spectroscopy, and first laser operation of a novel double molybdate compound – Tm:$KY(MoO_4)_2$. Diode-pumped, continuous-wave laser operation of Tm:$KY(MoO_4)_2$ configured in the form of crystalline films and plates could be obtained, yielding a maximum output power of 0.88 W near 1.9μm with a slope efficiency of 65.8% [13]. M. Nemec *et al.* reported on the measurement of the spectroscopic and laser parameters of the Er-doped $Gd_3Ga_3Al_2O_{12}$ crystal (Er:GGAG) in the temperature range of 80-340 K. The best power performance was obtained at 80 K, where they generated a maximum output power of 2.8W with a slope efficiency of 54% [14]. In another study, O Wada *et al.* employed terahertz(THz) time-domain spectroscopy and optical reflection measurements to study the dielectric properties of high refractive index oxyfluorosilicate (OFS) glasses and developed a

Optics EXPRESS

unified dielectric model for the sub-THz frequency region [15]. K. Hamamoto *et al*. further reported on the first measurement of the piezo-optic coefficients of ceramic YAG based on the four-point bending method and analyzed the resulting depolarization effects [16]. Finally, X. Ma *et al*. performed simulations to investigate the effect of heat load on the power performance of chirally-coupled-core fibers [17].

References

1. K. Hasse and C. Kränkel, "MHz-repetition rate fs-laser-inscribed crystalline waveguide lasers inscribed at 100 mm/s," Opt. Express **28**(8), 12011–12019 (2020).
2. V. Llamas, P. Loiko, E. Kifle, C. Romero, J. Vázquez de Aldana, Z. Pan, J. Serres, H. Yuan, X. Dai, H. Cai, Y. Wang, Y. Zhao, V. Zakharov, A. Veniaminov, R. Thouroude, M. Laroche, H. Gilles, M. Aguiló, F. Díaz, U. Griebner, V. Petrov, P. Camy, and X. Mateos, "Ultrafast laser inscribed waveguide lasers in Tm:CALGO with depressed-index cladding," Opt. Express **28**(3), 3528–3540 (2020).
3. Y. Baravets, P. Dvorak, F. Todorov, J. Ctyroky, P. Peterka, and P. Honzatko, "Broadly tunable laser based on novel metallic resonant leaky-mode diffraction grating," Opt. Express **28**(3), 4340–4346 (2020).
4. Q. Berthomé, A. Grisard, B. Faure, G. Souhaité, E. Lallier, J. Melkonian, and A. Godard, "Actively Q-switched tunable single-longitudinal-mode 2 um Tm:YAP laser using a transversally chirped volume Bragg grating," Opt. Express **28**(4), 5013–5021 (2020).
5. P. Mackonis and A. Rodin, "OPCPA investigation with control over the temporal shape of 1.2 ps pump pulses," Opt. Express **28**(8), 12020–12027 (2020).
6. L. Rishøj, F. Deng, B. Tai, J. Cheng, and S. Ramachandran, "Jitter-free, dual-wavelength, ultrashort-pulse, energetic fiber sources using soliton self-mode conversion," Opt. Express **28**(3), 4333–4339 (2020).
7. Y. Chen, T. Yao, L. Huang, H. Xiao, J. Leng, and P. Zhou, "2 kW high-efficiency Raman fiber amplifier based on passive fiber with dynamic analysis on beam cleanup and fluctuation," Opt. Express **28**(3), 3495–3504 (2020).
8. W. Wu, X. Li, F. Mei, D. Chen, and R. Yan, "30 mJ, 1 kHz sub-nanosecond burst-mode Nd:YAG laser MOPA system," Opt. Express **27**(25), 36129–36136 (2019).
9. F. Cassouret, A. Kausas, V. Yahia, G. Aka, P. Loiseau, and T. Taira, "High peak-power near-MW laser pulses by third harmonic generation at 355 nm in Ca5(BO3)3F nonlinear single crystals," Opt. Express **28**(7), 10524–10530 (2020).
10. G. Scurria, I. Manek-Hönninger, J. Carré, A. Hildenbrand-Dhollande, and S. Bigotta, "7 W mid-infrared supercontinuum generation up to 4.7 mu m in an indium-fluoride optical fiber pumped by a high-peak power thulium-doped fiber single-oscillator," Opt. Express **28**(5), 7672–7677 (2020).
11. J. Meyer, M. Lukowski, C. Hessenius, E. Wright, and M. Fallahi, "High peak power, sub-ps green emission in a passively mode locked W-cavity VECSEL," Opt. Express **28**(4), 5794–5800 (2020).
12. M. Li, O. Kitzler, and D. Spence, "Investigating single-longitudinal-mode operation of a continuous wave second Stokes diamond Raman ring laser," Opt. Express **28**(2), 1738–1744 (2020).
13. A. Volokitina, P. Loiko, A. Pavlyuk, S. Slimi, R. Solé, E. Salem, E. Kifle, J. Serres, U. Griebner, V. Petrov, M. Aguiló, F. Díaz, and X. Mateos, "Laser operation of cleaved single-crystal plates and films of Tm:KY(MoO4)2," Opt. Express **28**(7), 9039–9048 (2020).
14. M. Němec, P. Boháček, R. Švejkar, J. Šulc, H. Jelínková, B. Trunda, L. Havlák, M. Nikl, and K. Jurek, "Er:GGAG crystal temperature influence on spectroscopic and laser properties," Opt. Mater. Express **10**(5), 1249–1254 (2020).
15. O. Wada, D. Ramachari, C. Yang, T. Uchino, and C. Pan, "High refractive index properties of oxyfluorosilicate glasses and a unified dielectric model of silicate oxide glasses in the sub-terahertz frequency region," Opt. Mater. Express **10**(2), 607–621 (2020).
16. K. Hamamoto, R. Yasuhara, S. Tokita, M. Chyla, and J. Kawanaka, "Measurement of the piezooptic coefficient of ceramic YAG and analysis of depolarization," Opt. Mater. Express **10**(4), 891–898 (2020).
17. S. Zhu, J. Li, L. Li, K. Sun, C. Hu, X. Shao, and X. Ma, "Impact of the heat load on the laser performance of chirally-coupled-core fibers," Opt. Express **27**(26), 37522–37531 (2019).